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A VIEW FROM THE PENTHOUSE: USEFUL INFORMATION FOR THE WORLD OF BOILERS

Creep Failures

For alloys used in SH and RH, the operating temperature is often in the range where failures by creep are common. The ASME Boiler and Pressure Vessel Code recognizes creep as a high temperature design requirement. The Code sets allowable stresses in the creep range at that stress which will cause 1% deformation in 100,000 hours. What is creep? Some thoughts and observations:

Creep may be defined as a time dependent strain or deformation at constant stress at elevated temperature. The temperature at which creep begins depends on the alloy. For example, the common alloys used in SH and RH construction have the following approximate temperatures for the onset of creep:

Carbon steel	850°F
T-11	1000°F
T-22	1050°F
Stainless Steel (304, 321, 347)	1100°F

Boiler tubes that have failed by creep exhibit the following visible features:

1) bulging or blisters in the tube
2) thick-edged fractures and limited ductility
3) longitudinal "stress cracks" in either/both ID and OD oxide scales, and
4) external and internal oxidation.

The operating conditions that can lead to these failures are:

1) longterm operation at a slightly elevated temperature from design conditions.
2) internal scale/deposits impede heat flow and increase metal temperature, see Vol. 1, No. 1 of this newsletter
3) excessive flue gas temperature, and
4) diminished or impeded steam flow.

On a microstructural level the changes are equally dramatic, but not visible to the naked eye. The microstructures of creep failures are characterized by:

1) creep voids within the microstructure, and
2) grain boundary separation or cracks.

Creep failures may be caused by overheating the entire tube, or a very localized area. Figure 1 shows a typical creep failure. Note the narrow fissure and lack of ductility.

Useful metals are made up of individual crystals, which in turn are made up of individual atoms. The atoms within a crystal are arrayed in a regular pattern along specific crystallographic planes. At room temperatures deformation occurs by a mechanism called "slip"; that is, one plane of atoms slides over its neighbor. Microstructural appearance shows wavy lines within the grains, but no voids appear. As deformation continues, the sliding planes of atoms eventually run into a grain boundary. Further deformation distorts the grain boundary and the entire grain. Thus the microstructural features of room temperature deformation would show the following.

1) Up to about 15% elongation, there is little change in the microstructure (at 500x).
2) From about 15% to 20%, slip lines appear within individual crystals within the structure, see Figure 2.
3) At deformation greater than 20%, individual grains will begin to show (at 500x) elongation; nearly round grains become oval.
4) The hardness increases and the material is said to have "work hardened". All of this plastic flow makes the material harder. R_B hardness might increase from 70 to 85 or 90, depending on the material and amount of strain.

If a metal is deformed by creep its microstructure may appear nearly unaffected by the deformation. Specifically, slip lines that characterize deformation at ordinary temperatures are absent and the metal fails to work harden. The basic mechanism of creep deformation is not slip. However, another mechanism, grain boundary sliding does occur. Since the grain boundary is a zone of weakness at elevated temperatures, deformation occurs more readily by the relative motion of one grain to another by grain boundary sliding. Creep deformation may be thought of as whole grains moving as a block rather than as individual planes of atoms. There is little, if any, gross distortion to individual crystals.

Since grain boundaries are zones of weakness, it follows that a coarse-grained structure is stronger at elevated temperatures than a fine-grained material. Indeed, the Boiler Code specifies a minimum grain-size for 321 stainless steels to assure adequate creep strength.

Since creep occurs at elevated temperatures, there are other changes in the microstructure. For ferritic steels (SA-210, T-11, T-22, etc.) the appearance of the iron carbide phase or pearlite is altered. In new material iron carbide is in the form of blades or platelets. At elevated temperatures these blades become spherical and the material is said to have spheroidized. Thus the microstructure of a sample that has failed by creep, will contain both spherical carbide particles and creep voids.

For the stainless steels (304, 321, 347) there is no pearlite and the carbide phase appears as tiny particles along the grain boundaries. The microstructure of these alloys will show voids or grain boundary separation. Figures 3 and 4 show these changes in the microstructural appearance.

The creep damage itself may be confined to a small area, for example, pendant style elements that have experienced exfoliation of the steam side scale. Particles of iron oxide collect at the low point of the pendant. The The iron oxide acts as an insulating barrier to the transfer of heat and, on a local basis only, raises the tube metal temperature to the point where creep failures occur. The damage is confined to the area where the internal scale thickness, due to the exfoliation, is thick, 50 mils, while several inches away the scale thickness is considerably less; e.g. 2-5 mils. Wrapper tubes may also suffer creep damage as they are exposed to the gas pass where heat transfer is higher.

Creep damage may also be widespread where internal scale has raised tube metal temperatures 50° or 60°F from design. This is especially true in boilers that have been in service for 20 or 25 years and have never had the SH or RH chemically cleaned. In any case, competant metallurgical advice is needed to sort out the root causes of the failure.

Fig. 1. Failed RH tube, T-22.

Fig. 2. 20% deformation in 304H, 500x.

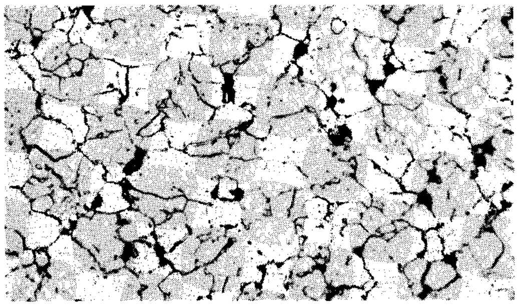

Fig. 3. Creep voids & spheroidization, T-22. 500x.

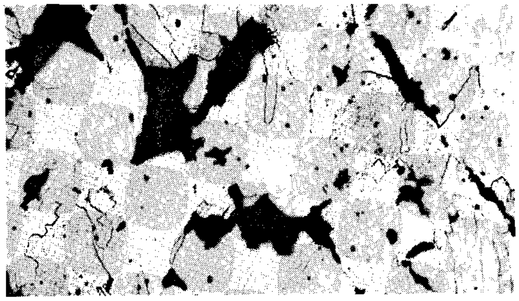

Fig. 4. Creep voids, 304H, 500x.

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